The Accelerator Complex in the Post Run II Era

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Project X Physics Workshop

November 9, 2009

Outline

- Fermilab Accelerator complex
- Current performance
  - Booster
  - Main Injector
- Accelerator complex after the Collider Run
  - NOvA
  - Muon Experiments (Mu2e, g-2)
  - TeV Stretcher
- Conclusions

Accelerator Complex

Accelerator Complex

- Linac
  - 400 MeV H^-
  - 35 mA
  - 5e11/turn on Booster Injection
- Booster
  - 8 GeV p
  - Multi-turn charge exchange injection
  - 9 - 15 Hz
    - Limitations on repetition rate – RF systems, reliability, and beam loss
    - RF Upgrades necessary to reach 15 Hz
  - Losses through ramp
  - 4.5e12 10 turns

Accelerator Complex

- Recycler:
  - 8 GeV permanent magnet ring
  - Used for antiproton storage and cooling.

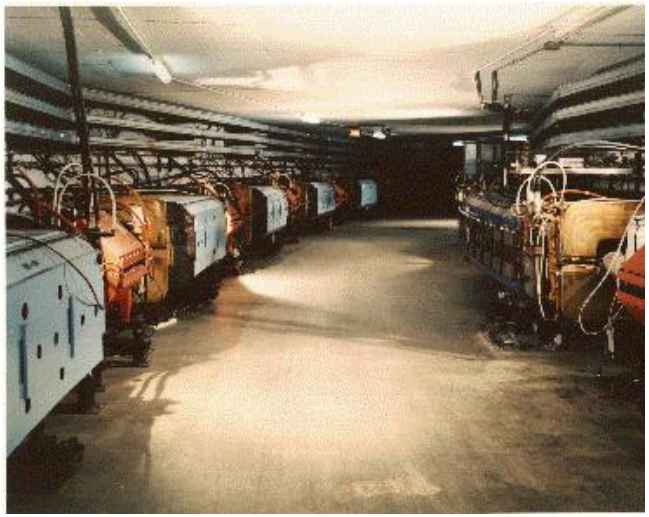
- Main Injector
  - 8 GeV / 120 GeV / 150 GeV
  - Min. 120 GeV cycle time (<1.5 sec)
  - 2.2 sec mixed mode cycle (NuMI+stacking)
  - Slow extraction (SY120)
    - Limited by losses (Slip Stacking)

Accelerator Complex

- AntiProton Source:
  - 2 Rings Accumulator and Debuncher
  - 8 GeV nominal
  - Slow ramp (lower energies)

  - Target station and associated beam lines

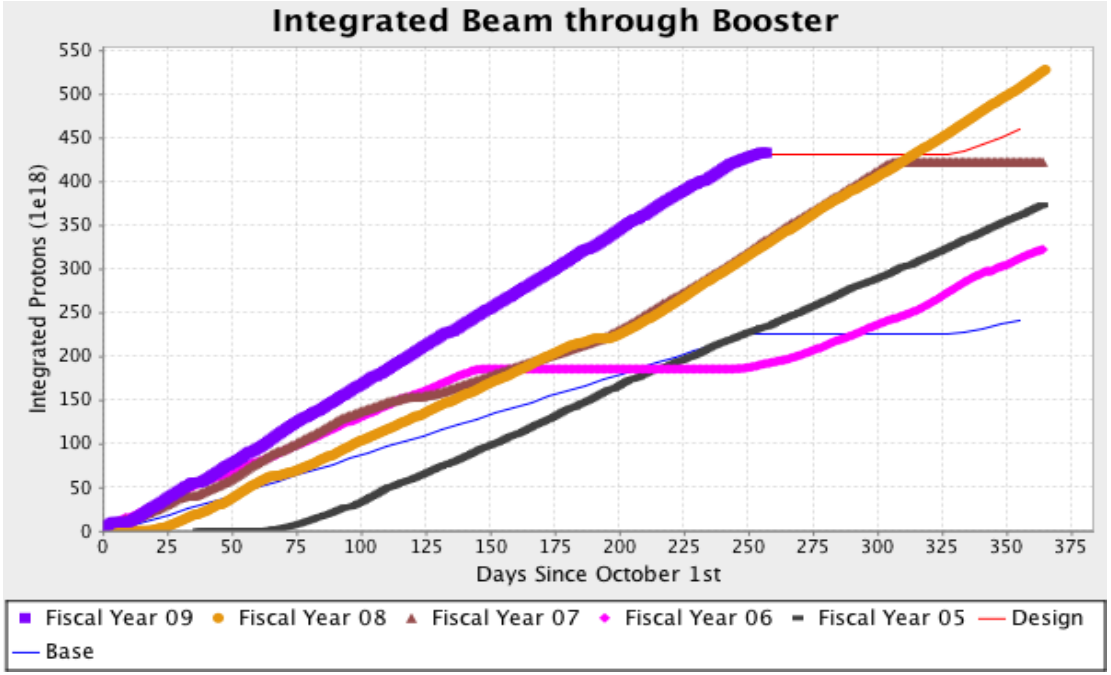
Debuncher

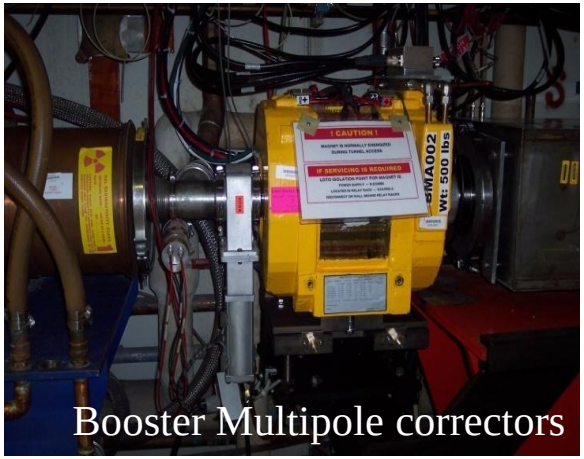


Accumulator

Addressing the Protons Demands

- Proton Plan:
  - Increase flux through Booster
  - Installation 2nd set of Booster Correctors Summer 09

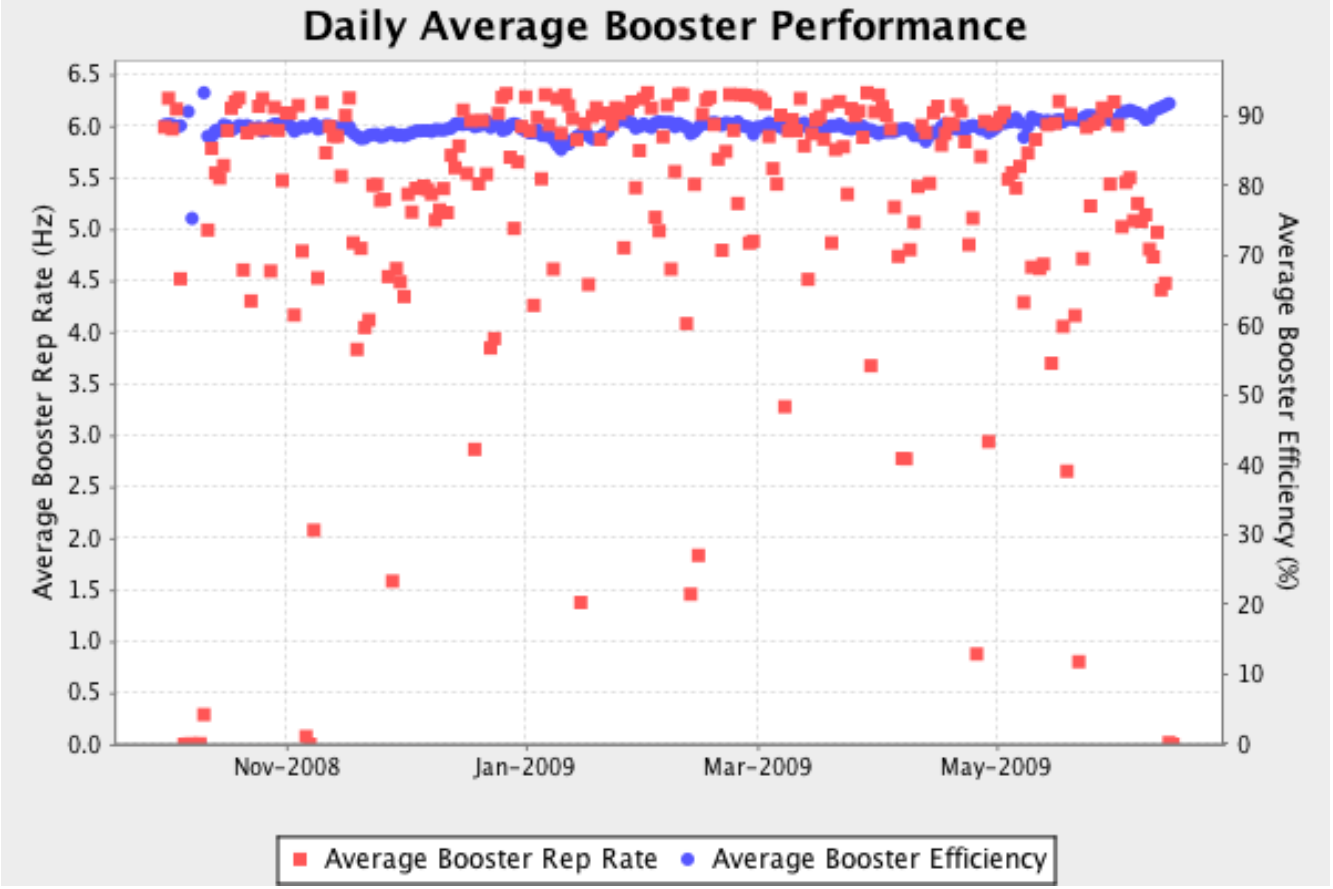




Booster FY09

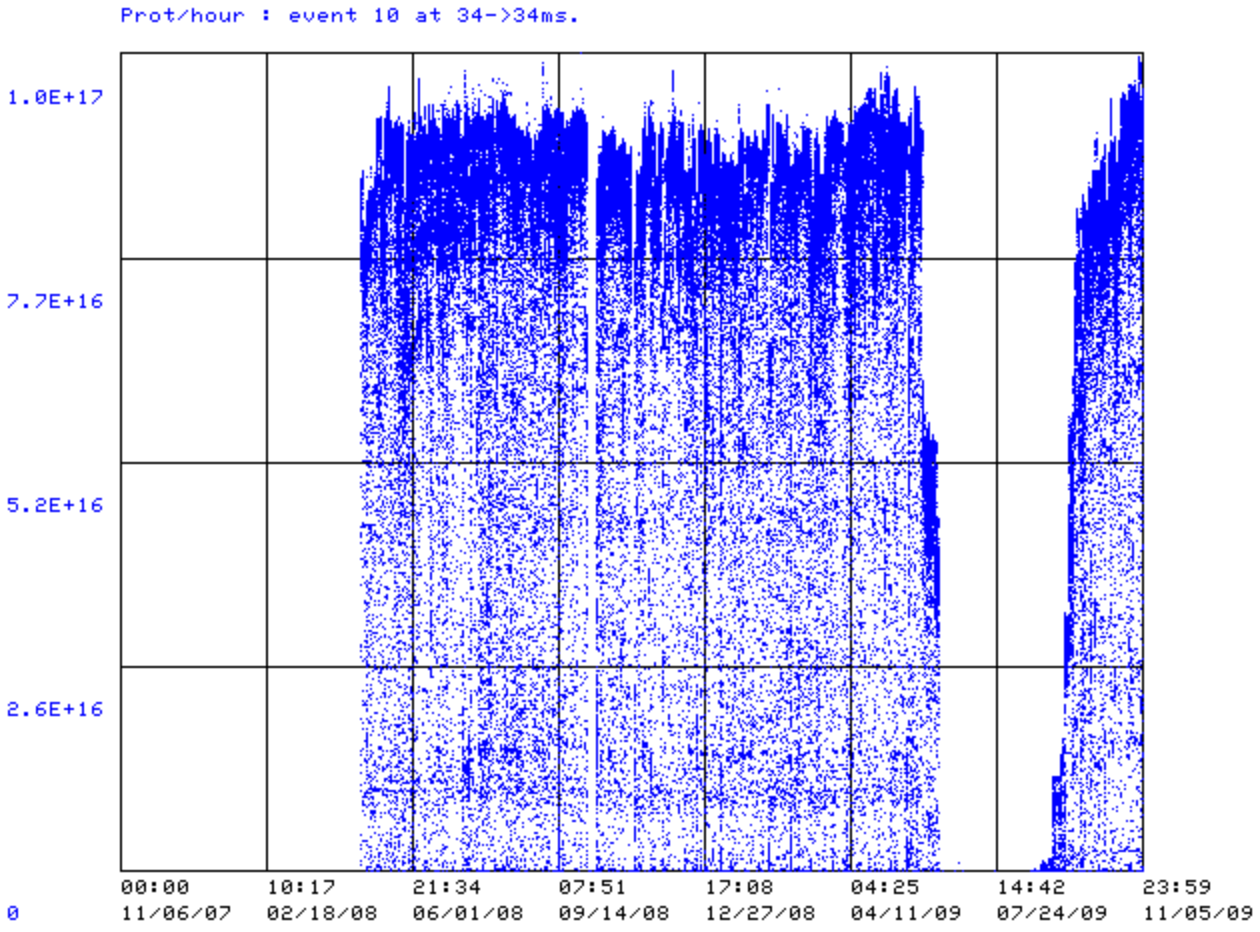
- Standard cycle: 2.2 seconds
  - 2 prepulse
  - 2 pbar
  - 9 NuMI
  - 3 BNB

7.3 Hz, 6.4 Hz with beam

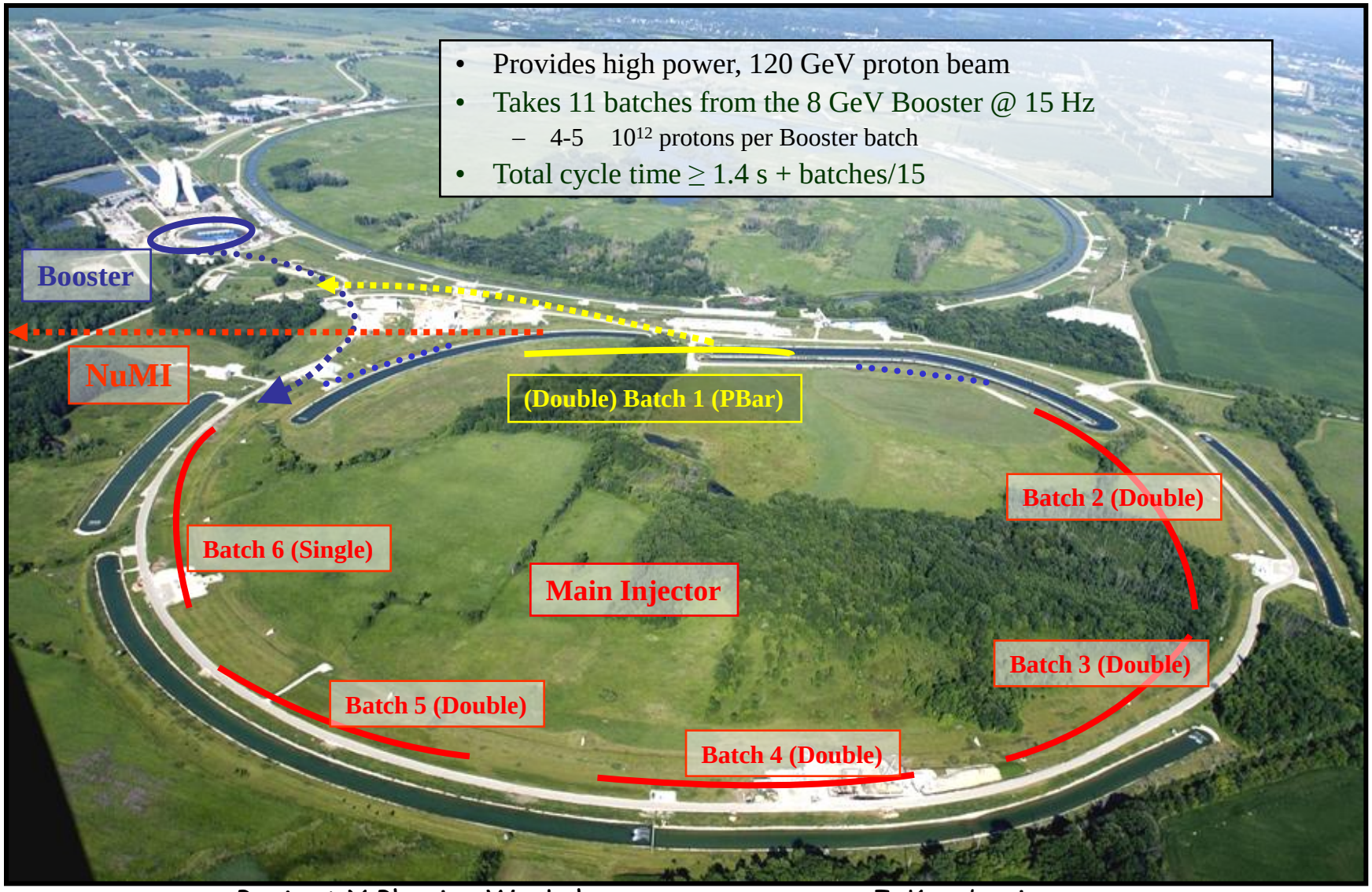


Run 4th to BNB: held off due to reliability concerns

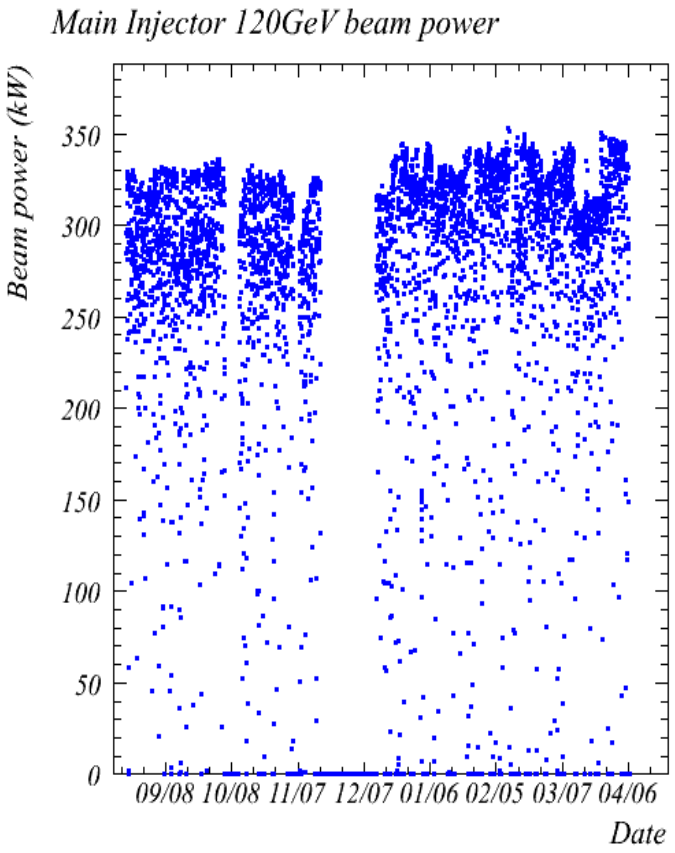
Booster Protons per hour



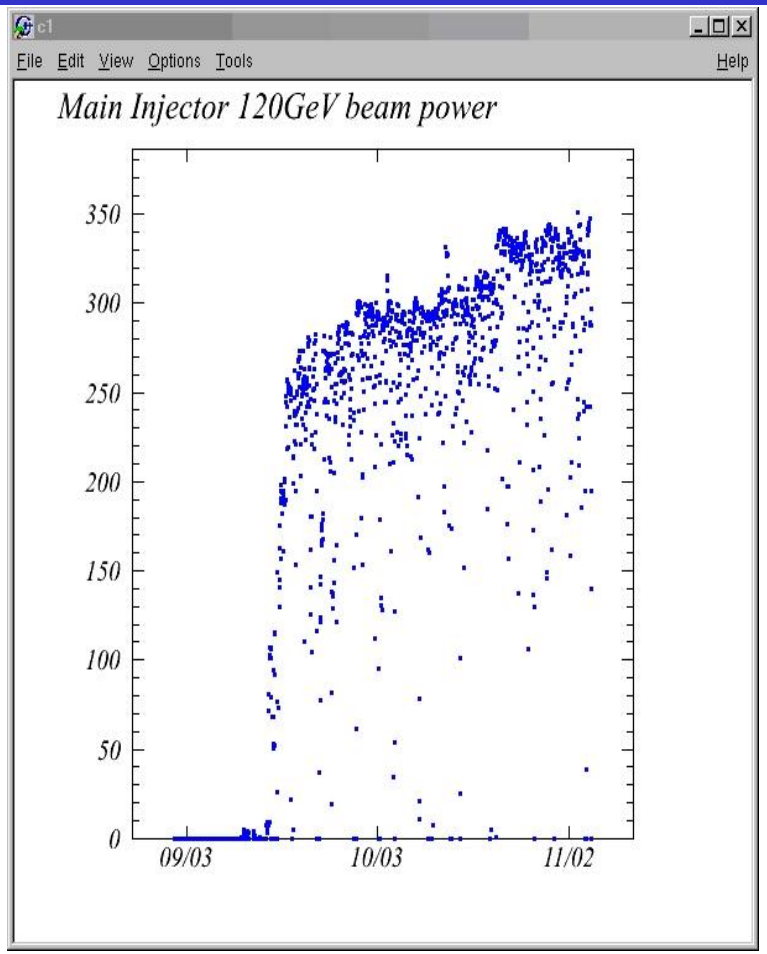
Main Injector High Power Operation (Mixed Mode)



MI Beam Power

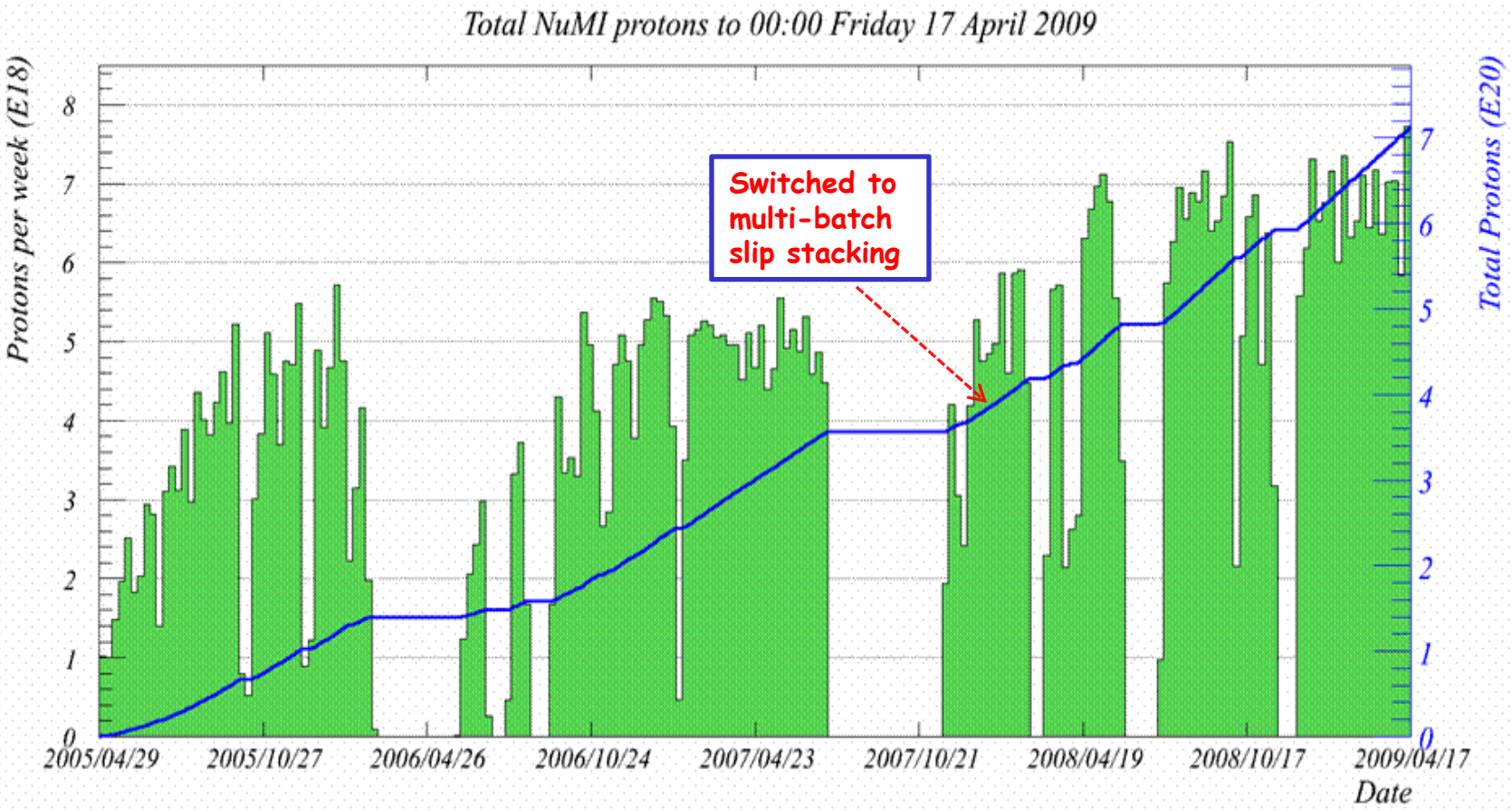


•**MI 120 GeV power from Aug. 2008 till May 2009.**



•**MI 120 Gev power since the startup.**

Weekly protons to NuMI Target



Accelerator complex after Collider Run

- Recycler ring is transformed into a proton injector for Main Injector in order to reduce the MI cycle time and to increase the MI 120 GeV beam power to 700 KW operation for NOvA.
- Booster rep rate increases to 10.5 Hz and upgrades are in place for 15 Hz operation.
- The antiproton rings will be reconfigured for muon physics at 8 GeV.
- Tevatron can be used for fixed target physics at 120 (150) GeV.

Current Accelerator Schedule

Draft 2010-13 Fermilab Accelerator Experiments' Run Schedule

Typically Revised Annually - This Version from October, 2009

Calendar Year		2010	2011	2012	2013
Tevatron Collider		CDF & DZero	CDF & DZero	OPEN	OPEN
Neutrino Program	B	MiniBooNE	MiniBooNE		OPEN
		OPEN	OPEN		MicroBooNE
	MI	MINOS	MINOS		OPEN
		MINERvA	MINERvA		MINERvA
		ArgoNeuT			
				NOvA	NOvA
SY 120	MT	Test Beam	Test Beam		Test Beam
	MC	OPEN	OPEN		OPEN
	NM4	E-906/Drell-Yan	E-906/Drell-Yan		E-906/Drell-Yan

This draft schedule is meant to show the general outline of the Fermilab accelerator experiments schedule, including unscheduled periods.

Major components of the schedule include shutdowns:
In Calendar 2010, a 4-6 week shutdown for maintenance is shown.
In Calendar 2011, no shutdown for maintenance is shown.
A 2012-3 11-month shutdown is shown to upgrade the proton source and change the NuMI beam to the Medium Energy (ME) config.

RUN/DATA

STARTUP/COMMISSIONING

INSTALLATION

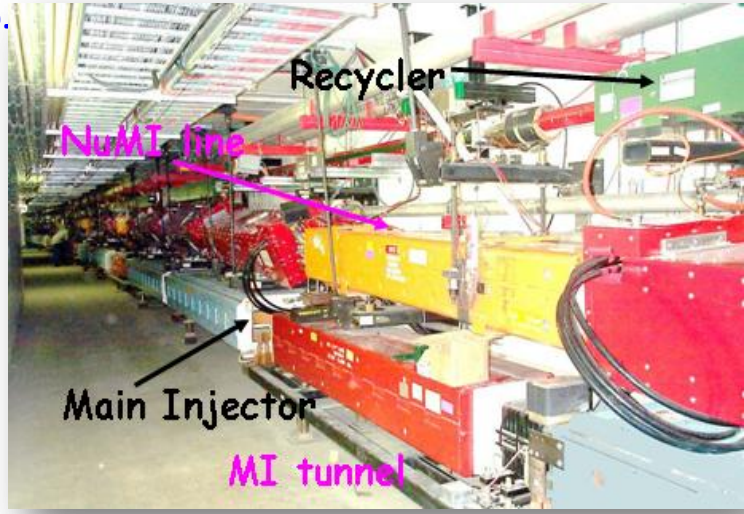
M&D (SHUTDOWN)

19-Oct-09

700 kW for NOvA

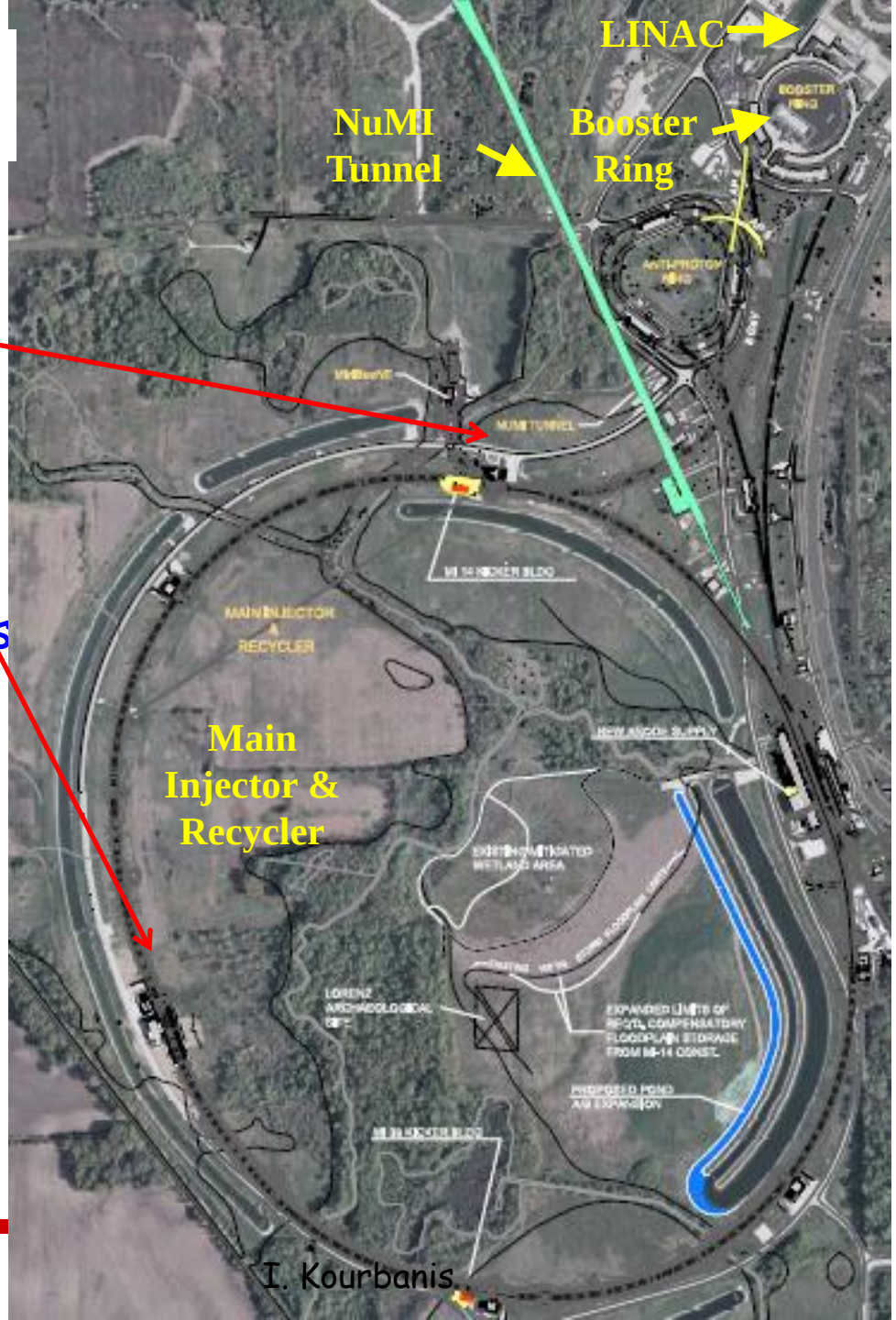
- When Collider program concludes, use the Recycler as a proton pre-injector
  - Use the Recycler to accumulate protons from the Booster while MI is accelerating
  - Can save 0.4 s for each 6 Booster batches injected
- Recycler momentum aperture is large enough to allow slip-stacking operation in Recycler, for up to 12 Booster batches injected
  - 6 batches are slipped with respect to the other 6 and, at the time they line up, they are extracted to MI in a single turn and there re-captured and accelerated
  - Main Injector will run at its design acceleration rate of 240 GeV/s (1.3s cycle time) (operates at 204 GeV/s presently)
  - 4.3 10^{12} p/batch, 95% slip-stacking efficiency
  - 4.9×10^{13} ppp at 120 GeV every 1.333 s

⇒ **700 kW**

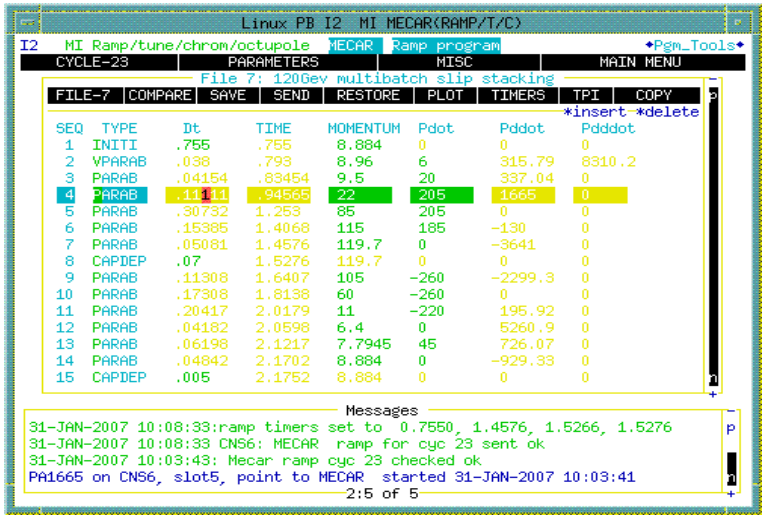


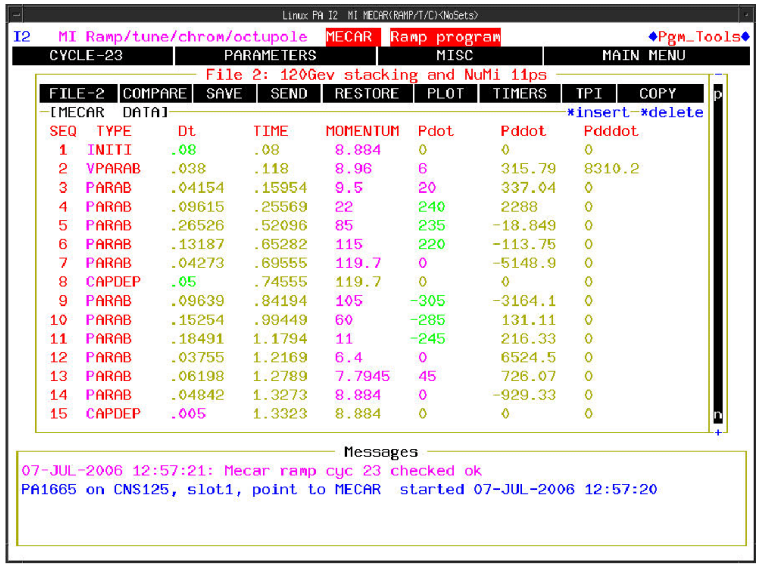
Main Accelerator Upgrades

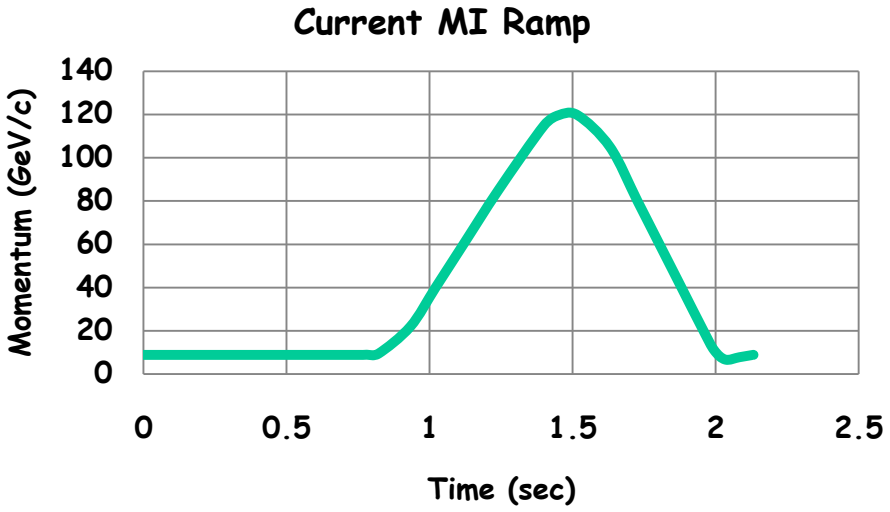
- Recycler Ring, RR
  - New injection line into RR
  - New extraction line from RR
  - New 53 MHz RF system
  - New low level RF system
  - New kickers
- Main Injector
  - Two additional 53 MHz cavities (total 20 instead of 18)
  - Quad Power Supply Upgrade
- NuMI
  - Change to medium energy ν beam configuration (new target)
  - Cooling & power supply upgrades

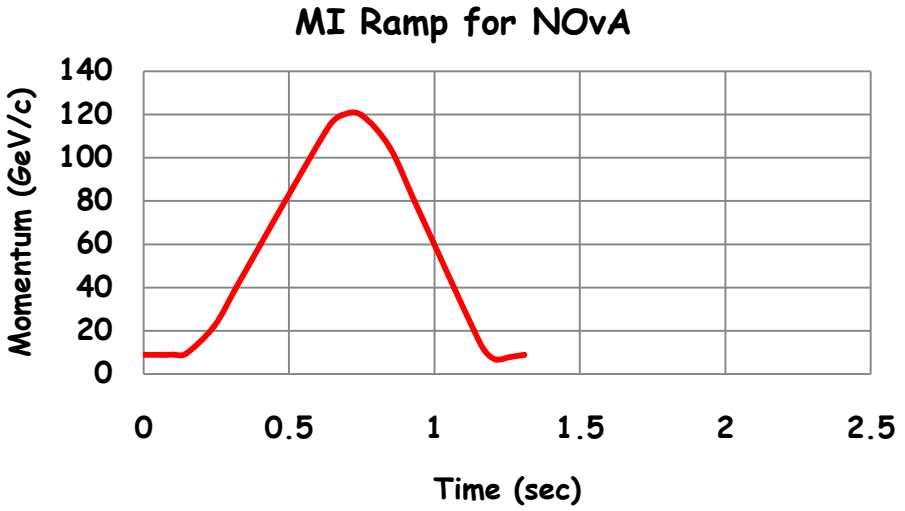


MI Ramp

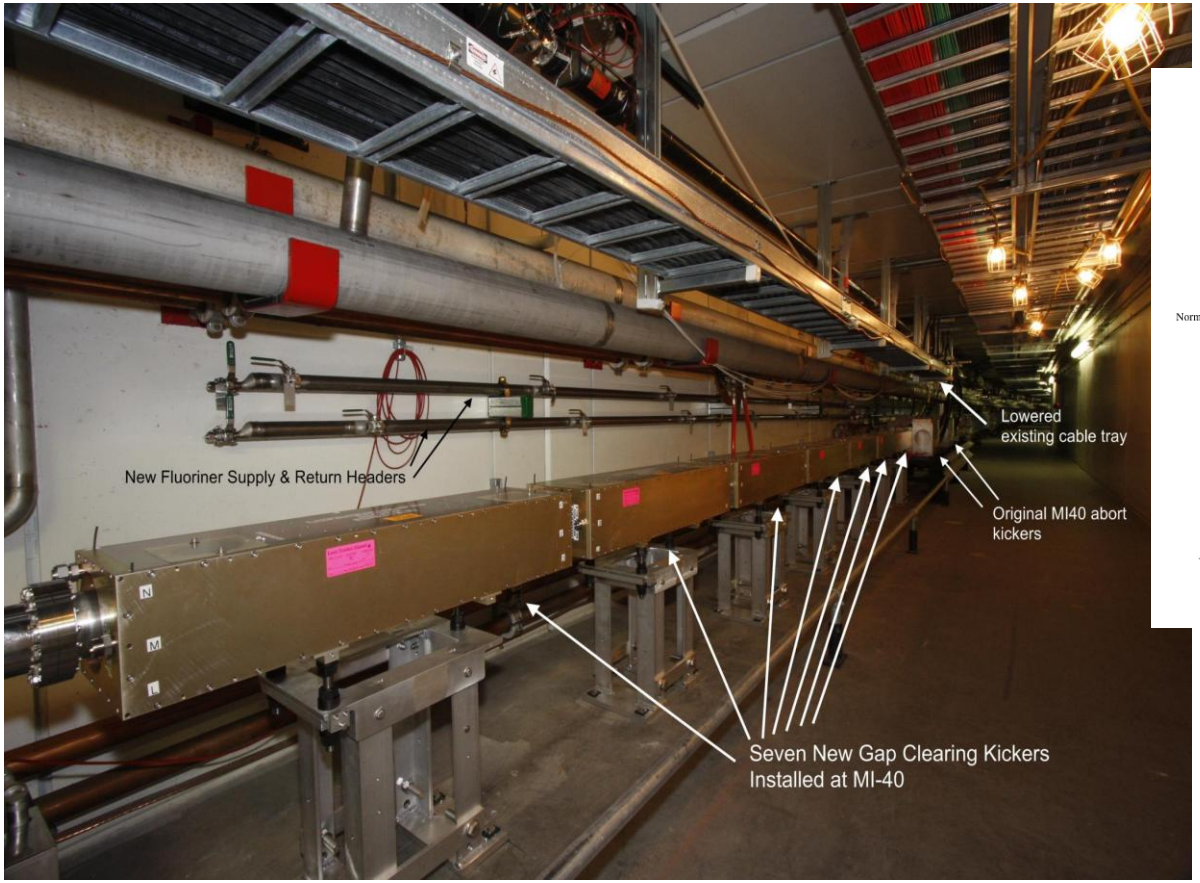

Linux PB I2 MI MECAR(RAMP/T/C)
I2 MI Ramp/tune/chrom/octupole MECAR Ramp program ♦Pgm_Tools♦
CYCLE-23 PARAMETERS MISC MAIN MENU
File 7: 120Gev multibatch slip stacking
FILE-7 COMPARE SAVE SEND RESTORE PLOT TIMERS TPI COPY
*insert *delete
SEQ TYPE Dt TIME MOMENTUM Pdot Pddot Pdddot
1 INITI .755 .755 8.884 0 0 0
2 VPARAB .038 .793 8.96 6 315.79 8310.2
3 PARAB .04154 .83454 9.5 20 337.04 0
4 PARAB .11111 .94565 22 205 1665 0
5 PARAB .30732 1.253 85 205 0 0
6 PARAB .15385 1.4068 115 185 -130 0
7 PARAB .05081 1.4576 119.7 0 -3641 0
8 CAPDEP .07 1.5276 119.7 0 0 0
9 PARAB .11308 1.6407 105 -260 -2299.3 0
10 PARAB .17308 1.8138 60 -260 0 0
11 PARAB .20417 2.0179 11 -220 195.92 0
12 PARAB .04182 2.0598 6.4 0 5260.9 0
13 PARAB .06198 2.1217 7.7945 45 726.07 0
14 PARAB .04842 2.1702 8.884 0 -929.33 0
15 CAPDEP .005 2.1752 8.884 0 0 0
Messages
31-JAN-2007 10:08:33:ramp timers set to 0.7550, 1.4576, 1.5266, 1.5276
31-JAN-2007 10:08:33 CNS6: MECAR ramp for cyc 23 sent ok
31-JAN-2007 10:03:43: Mecar ramp cyc 23 checked ok
PA1665 on CNS6, slot5, point to MECAR started 31-JAN-2007 10:03:41
2:5 of 5

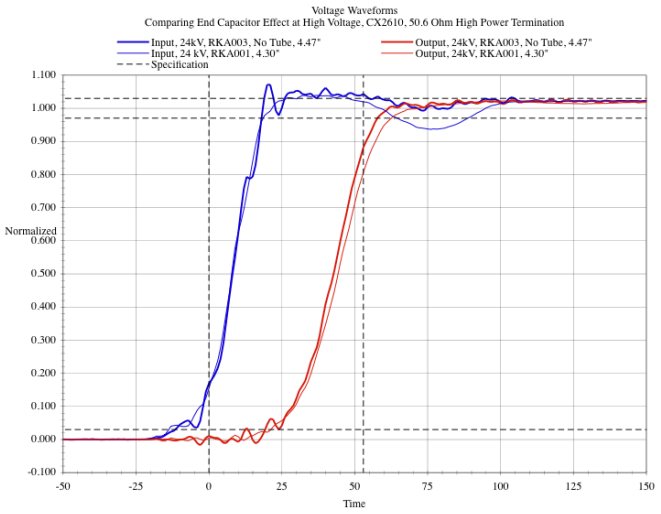

I2 MI Ramp/tune/chrom/octupole MECAR Ramp program ♦Pgm_Tools♦
CYCLE-23 PARAMETERS MISC MAIN MENU
File 2: 120Gev stacking and NuMi 11ps
FILE-2 COMPARE SAVE SEND RESTORE PLOT TIMERS TPI COPY
[MECAR DATA]
*insert *delete
SEQ TYPE Dt TIME MOMENTUM Pdot Pddot Pdddot
1 INITI .08 .08 8.884 0 0 0
2 VPARAB .038 .118 8.96 6 315.79 8310.2
3 PARAB .04154 .15954 9.5 20 337.04 0
4 PARAB .09615 .25569 22 240 2288 0
5 PARAB .26526 .52096 85 235 -18.849 0
6 PARAB .13187 .65282 115 220 -113.75 0
7 PARAB .04273 .69555 119.7 0 -5148.9 0
8 CAPDEP .05 .74555 119.7 0 0 0
9 PARAB .09639 .84194 105 -305 -3164.1 0
10 PARAB .15254 .99449 60 -285 131.11 0
11 PARAB .18491 1.1794 11 -245 216.33 0
12 PARAB .03755 1.2169 6.4 0 6524.5 0
13 PARAB .06198 1.2789 7.7945 45 726.07 0
14 PARAB .04842 1.3273 8.884 0 -929.33 0
15 CAPDEP .005 1.3323 8.884 0 0 0
Messages
07-JUL-2006 12:57:21: Mecar ramp cyc 23 checked ok
PA1665 on CNS125, slot1, point to MECAR started 07-JUL-2006 12:57:20


Current MI Ramp
Momentum (GeV/c)
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Time (sec)


MI Ramp for NOvA
Momentum (GeV/c)
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
Time (sec)

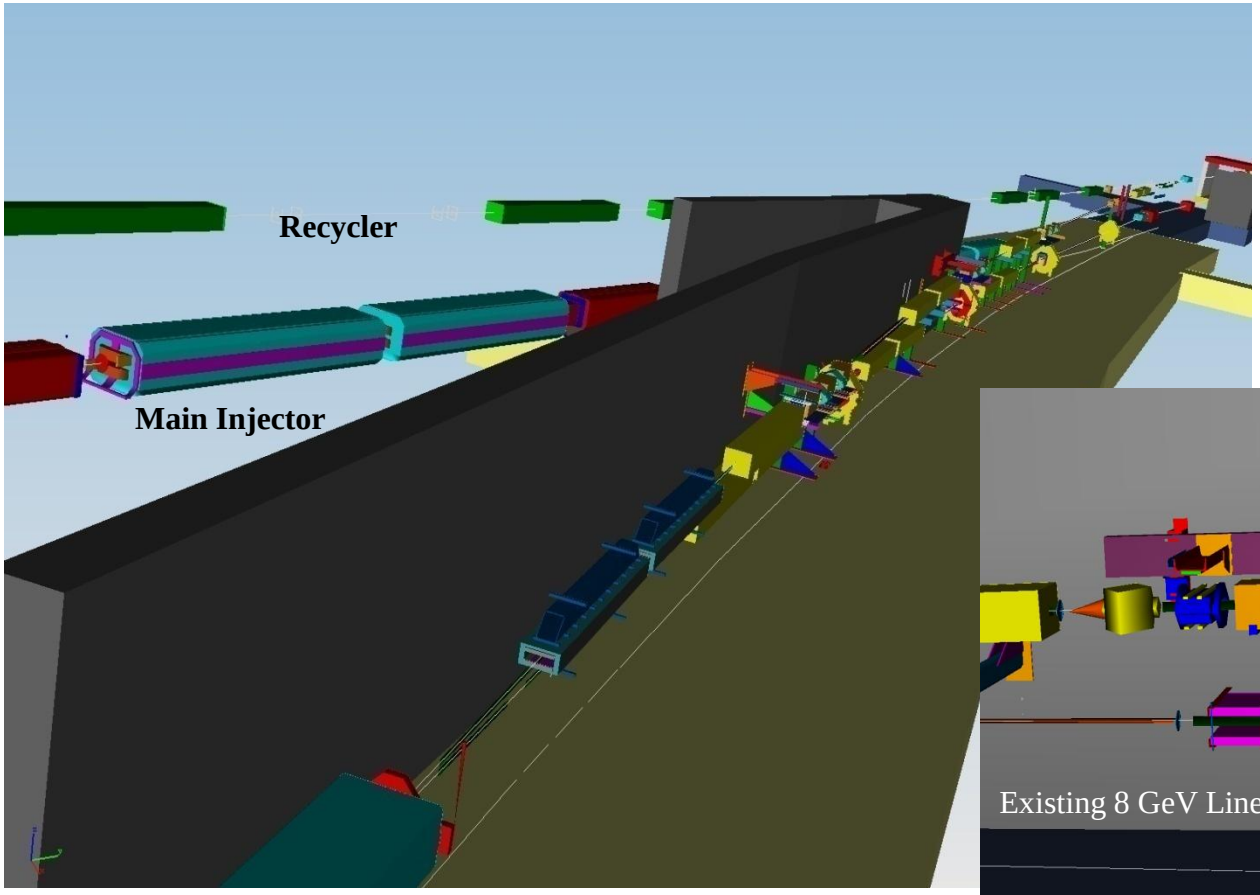
First kickers installed in the MI tunnel (NOvA)

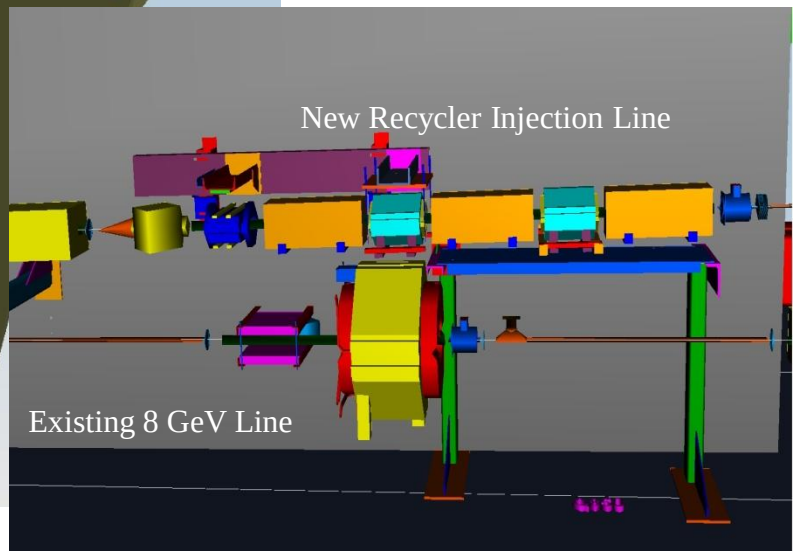




•The kicker gap clearing kickers are the most technically challenging of the new kickers required for NOvA (Rise/fall time <57nsec).

RR Injection Line Modeling (NOvA)



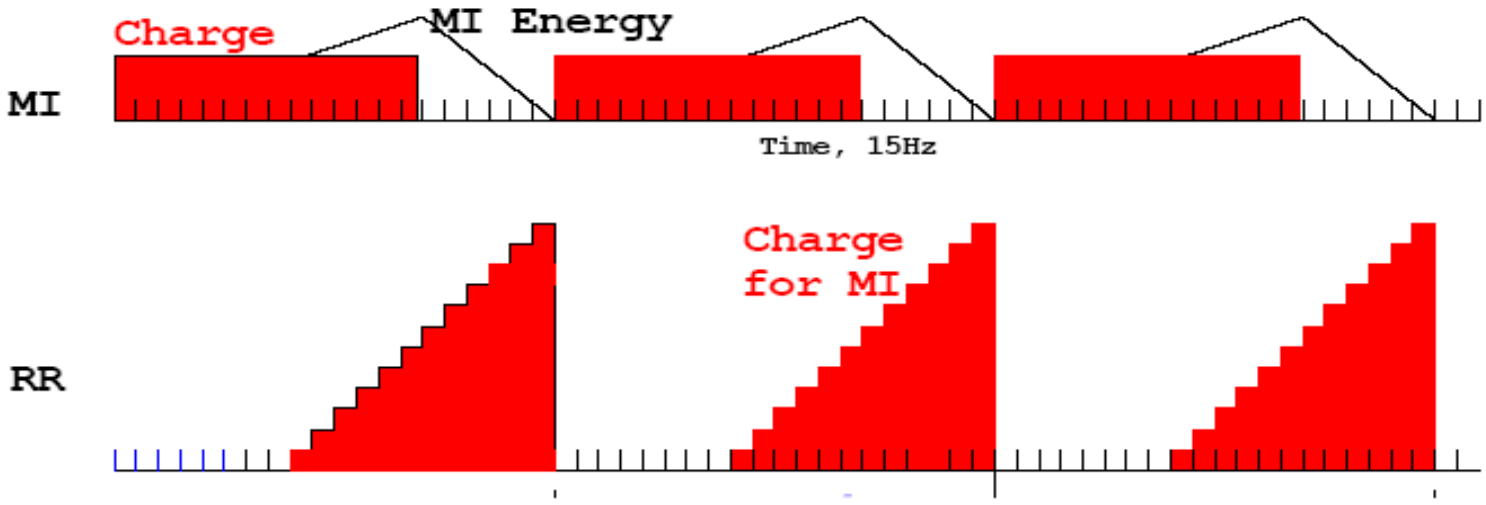


New Accelerator Service Buildings (NOvA)

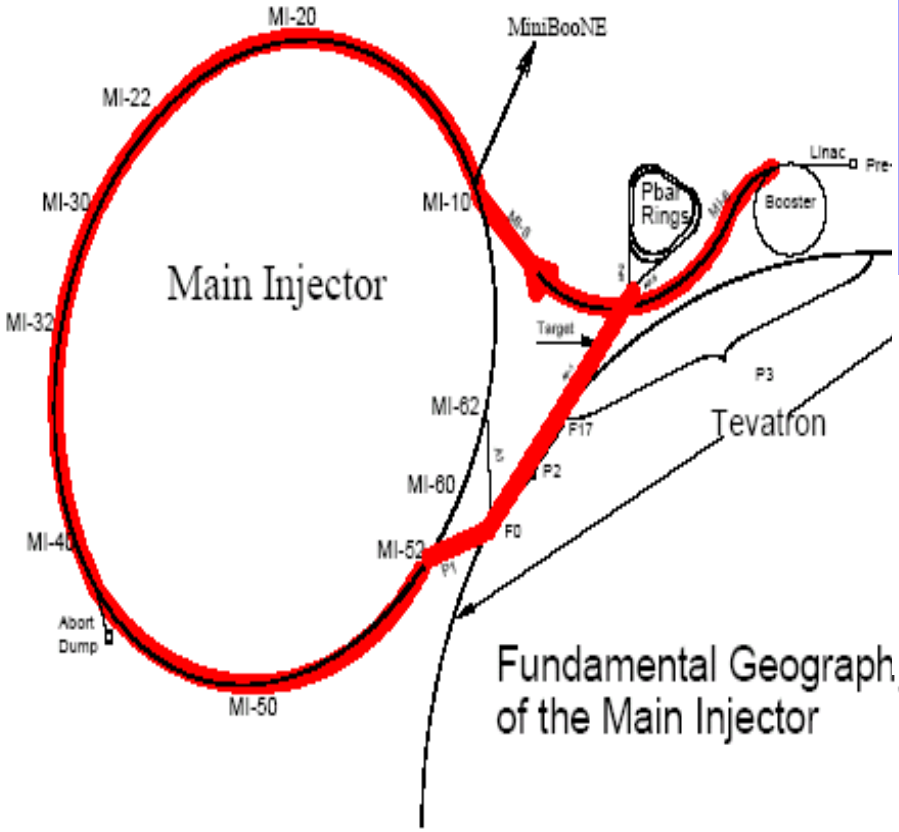
4th Anode Supply Building

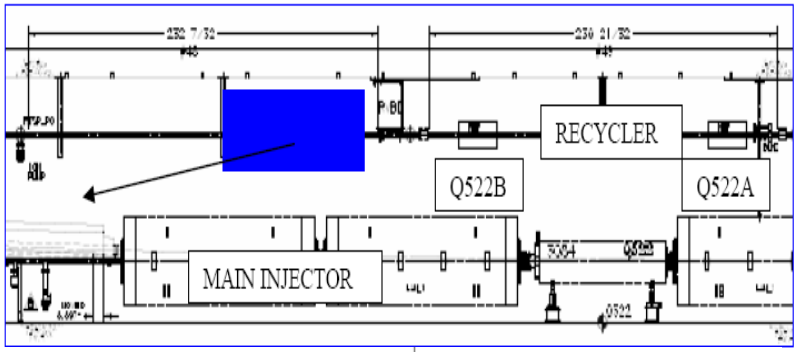
8 GeV Experimental Facility

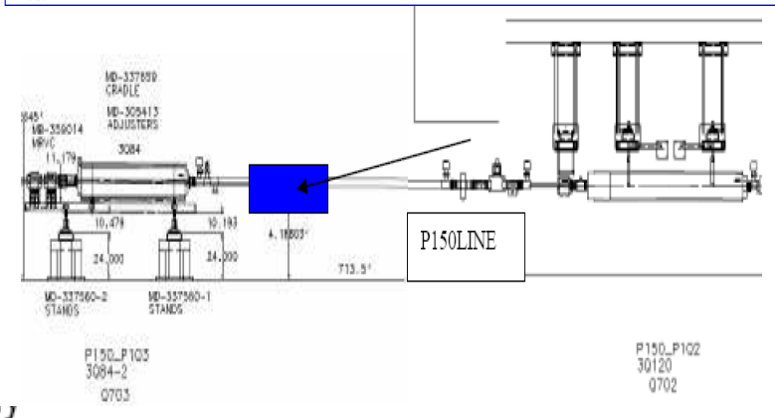
- During the 700kW NOVA era, it takes 0.8 seconds to fill the Recycler at 15Hz
- Since the Main Injector ramp requires 1.33 seconds, the Recycler is empty and available for 0.53 seconds (8 Booster cycles).
- If the Recycler is connected to the current P1 line, beam can be sent to the Accumulator via the P1-P2-AP3 line (as it is done now) with no civil construction.



The Recycler Boomerang*







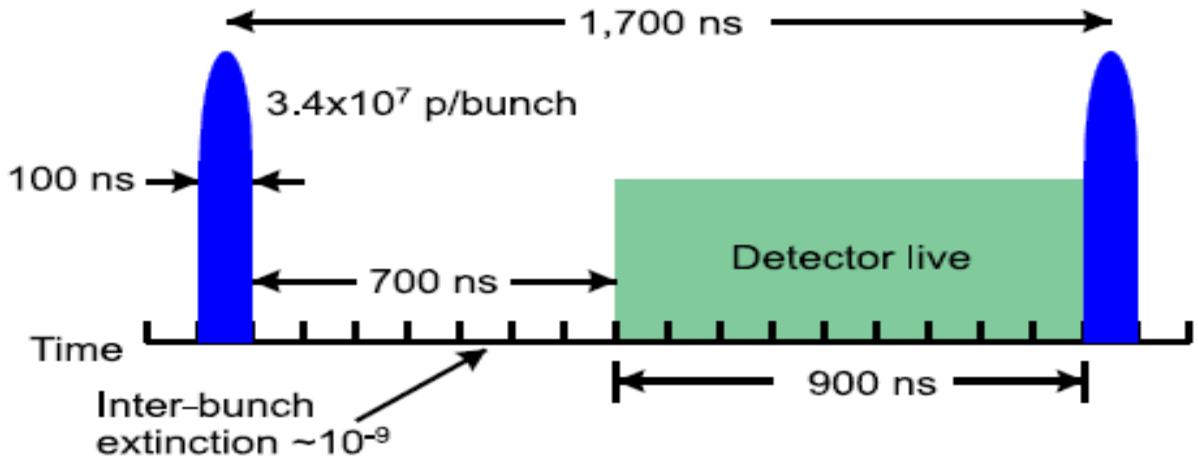
*C. Ankenbrandt et al

•A beamline connecting RR to P150 line is critical for delivering protons to the Antiproton Rings.

Booster 15 Hz Operation

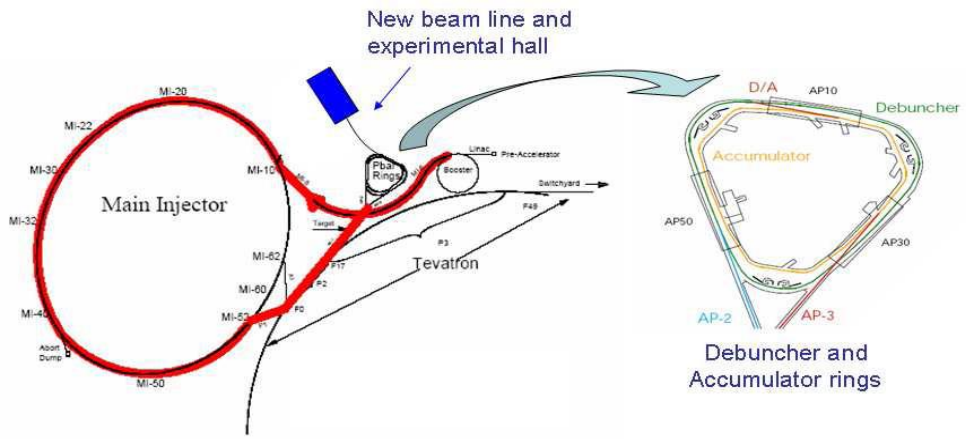
- Booster will be required to run beam in all available cycles.
- The remaining components upgrades required for 15 Hz Booster operation are rf related.
  - Implement cooling on the end cones of the ferrite-loaded tuners.
  - Replace the West Gallery Ferrite Bias Supply transformers (10)
  - Replace the East and West Gallery Anode Power Supply transformers.
  - The solid state upgrade of the rf amplifiers is critical for reliability
- Booster operation at 15 Hz with 4.3E12 ppp corresponds to 2.2x10E17 protons per hour while the current limit dictated by losses is 1.4xE17 protons per hour.
  - Installation of Booster correctors is expected to help with losses.
  - Plan to replace the current source and the Cockcroft-Walton in order to reduce the emittances from Linac and help the losses.

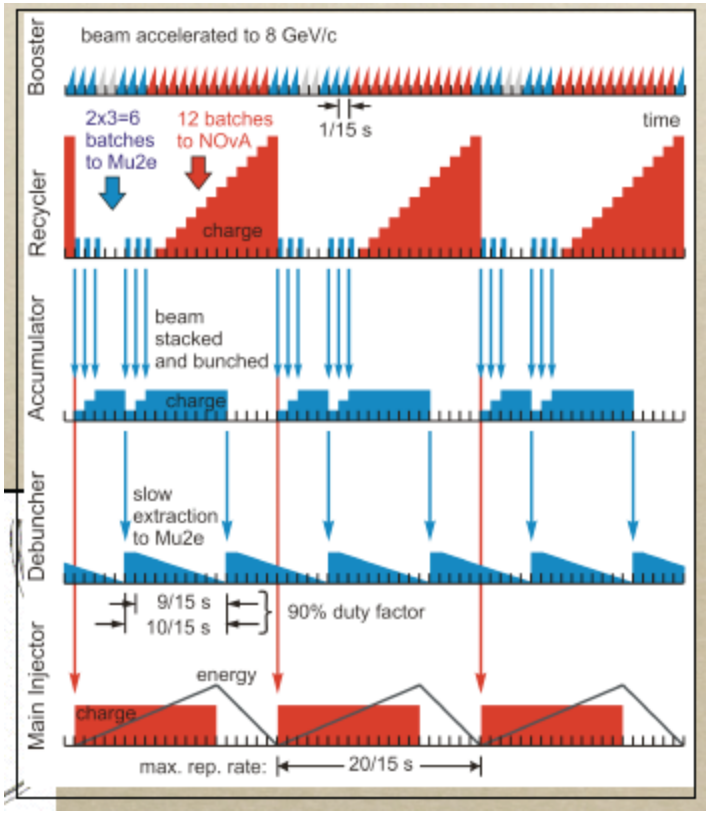
Mu2e Beam requirements



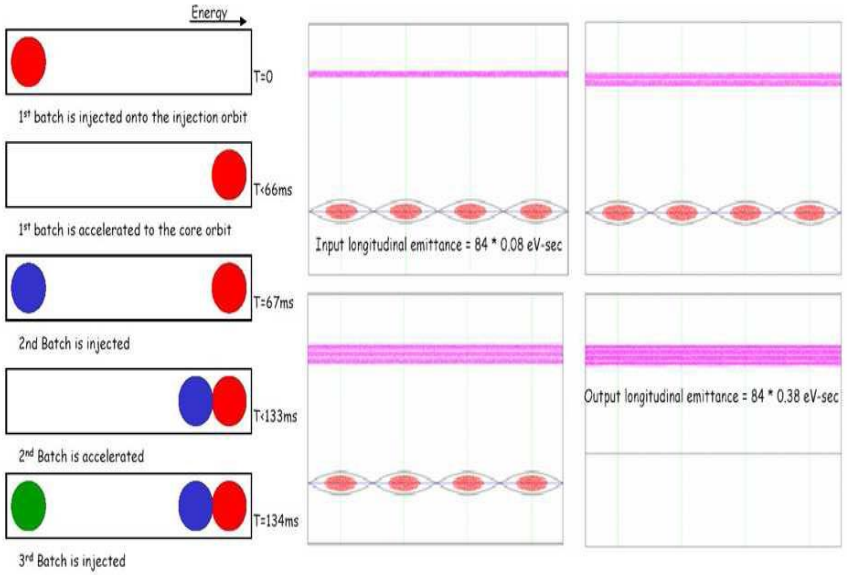
- Beam delivered in short time bursts (<200 nsec), separated by intervals of about 1.7 micro sec.
- Suppression of the primary proton between bursts by a factor of 10E9.
- Total of 4x10E20 protons on target during one or two years of running.

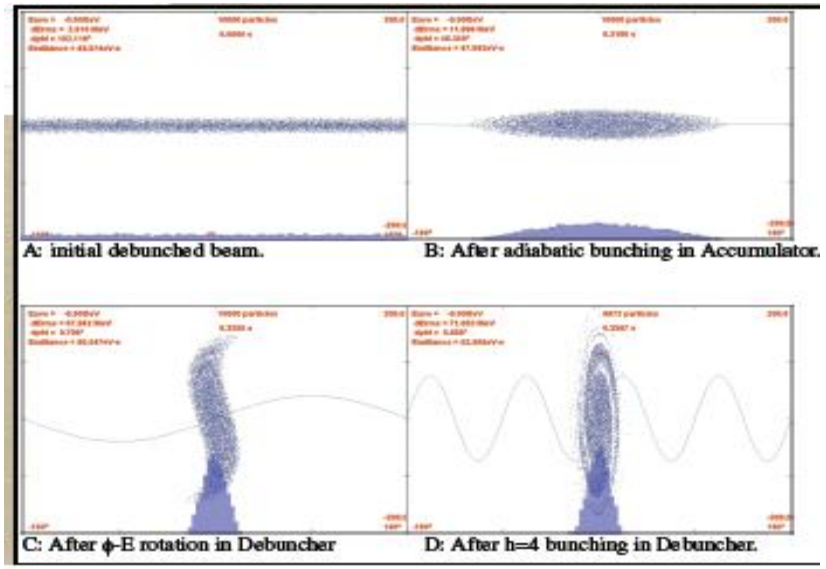
Original Mu2e Proposal





Bunch Formation—Mu2e Proposal

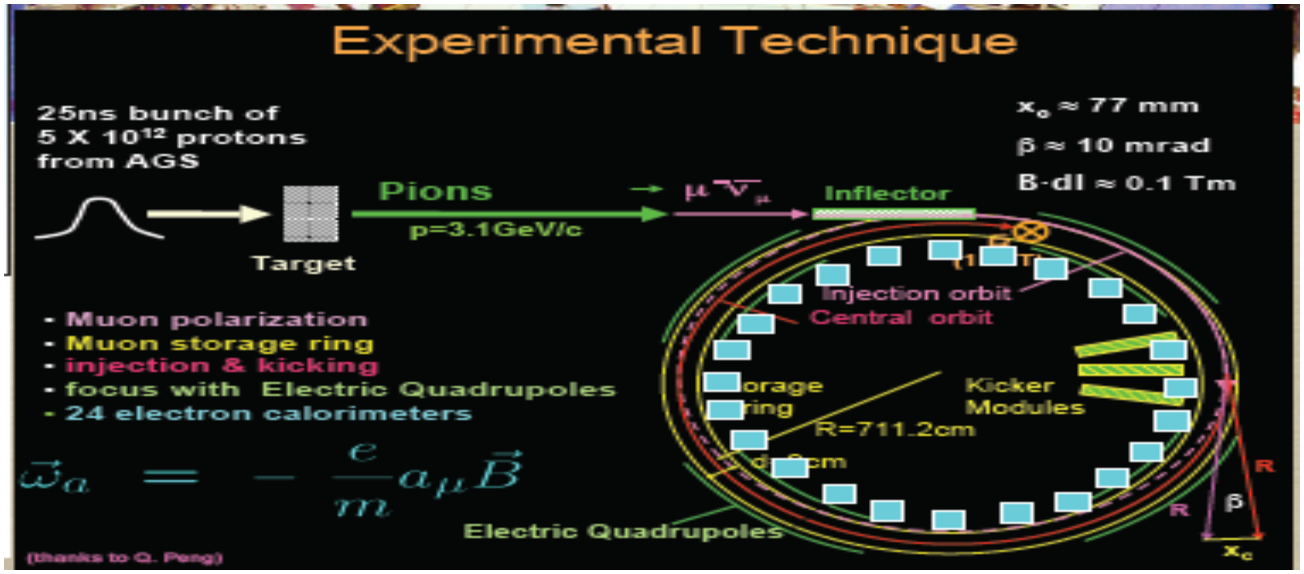




- Momentum stack 3 Booster batches in Accumulator.
- Form single bunch; transfer to Debuncher.
- Phase rotate and recapture.
- 40 nsec bunch, Dp/p~0.8%(rms)

- Alternate scenarios that avoid the large momentum spread and space charge tune shift have been proposed.

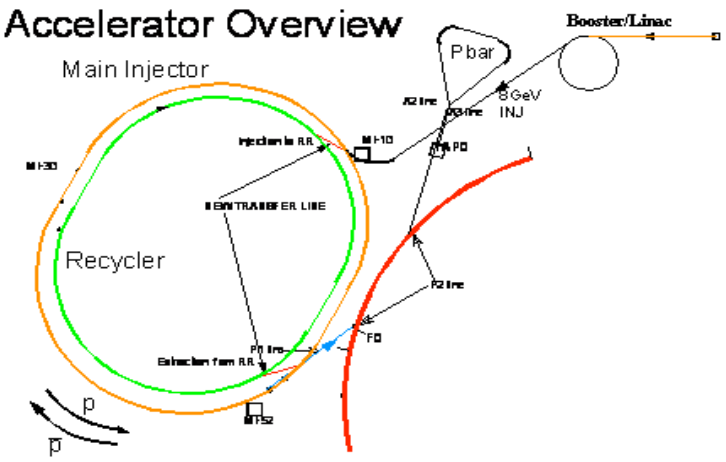
g-2 Beam Requirements



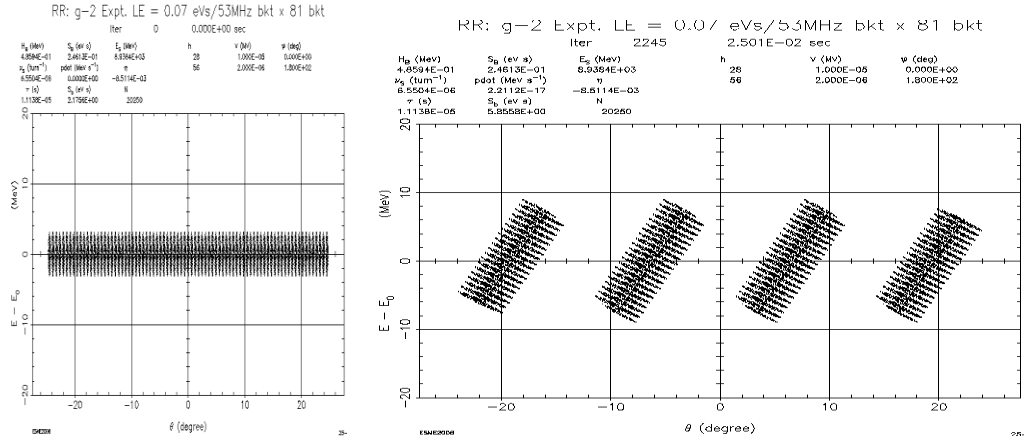
- 3.09 GeV/c muons into an existing muon storage ring.
- Beam pulsed with 100 nsec or less separated on the scale of about 10 msec (allowing muons to decay and data to be collected).
- Total of 2x10E20 protons.

Bunch Formation for g-2

- Generate 4 "mis-matched" 2.5 MHz bunches per Booster batch in Recycler that phase rotate in 24 msec; extract one every 12 msec.
- Target at AP0 target Hall; use pbar rings as 1-pass "decay channel" for pions; accumulate muons in g-2 ring.

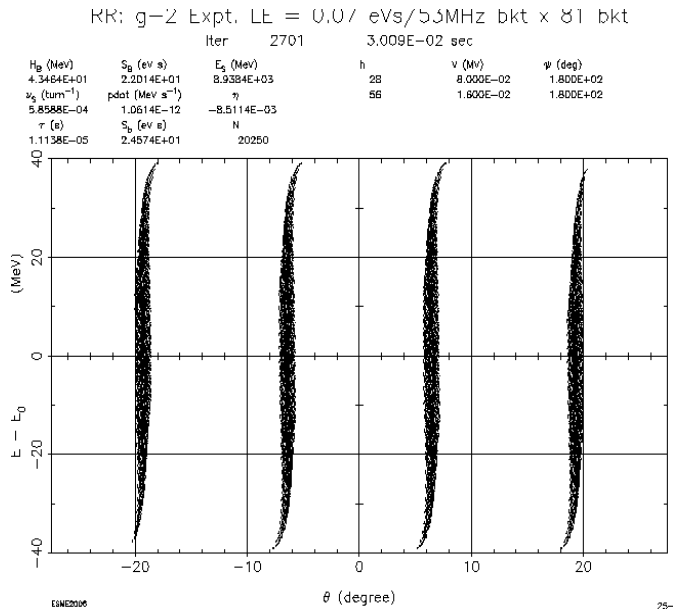


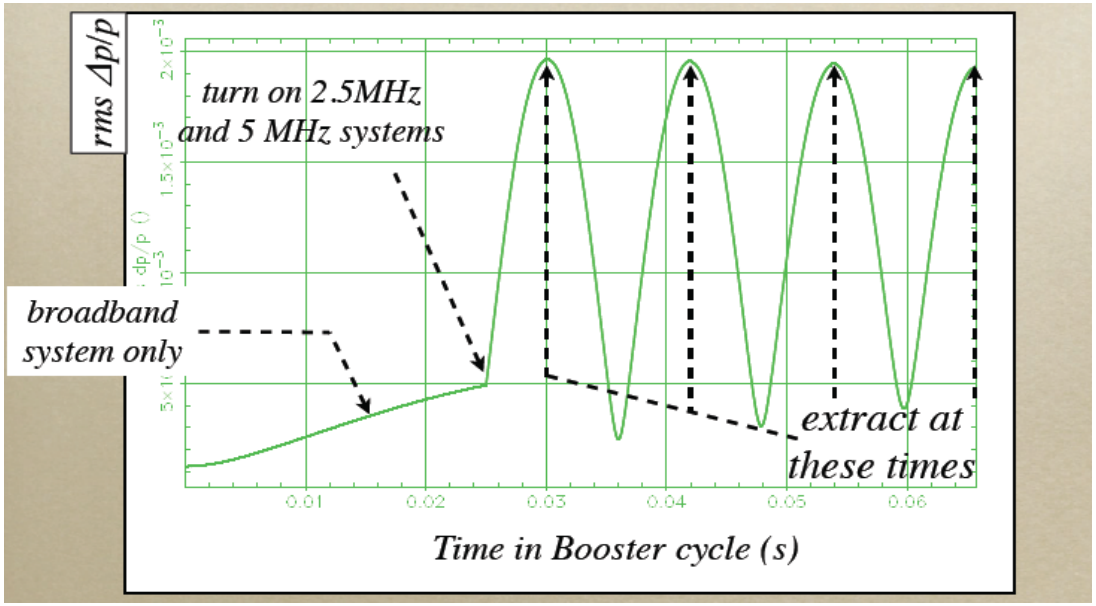
Beam simulations for g-2



- **Requires a 4KV barrier bucket rf system**
- **Uses the 2.5+5MHz coalescing rf from MI**

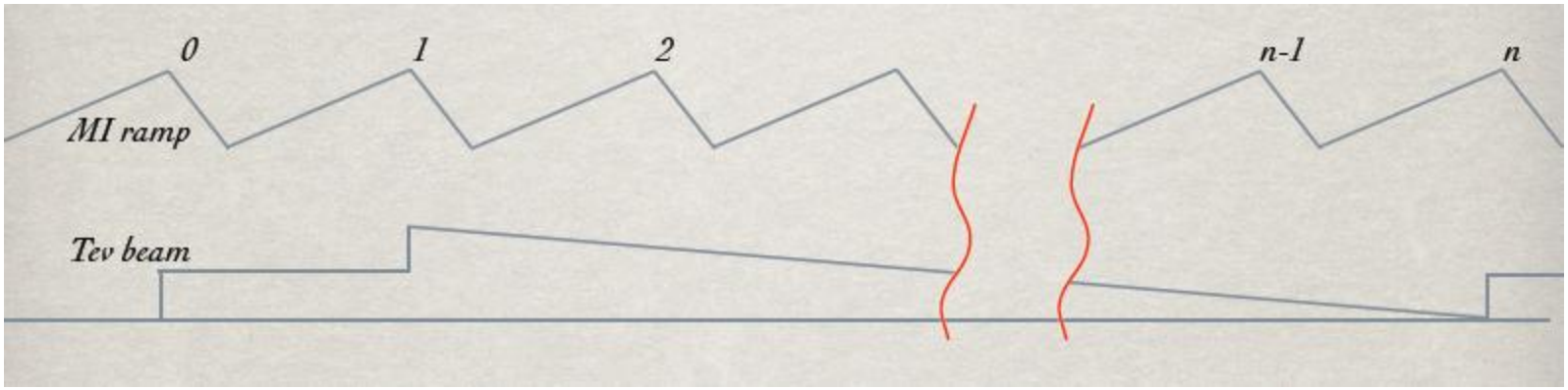
C.M. Bhat and J.A. MacLachlan





Tevatron Stretcher

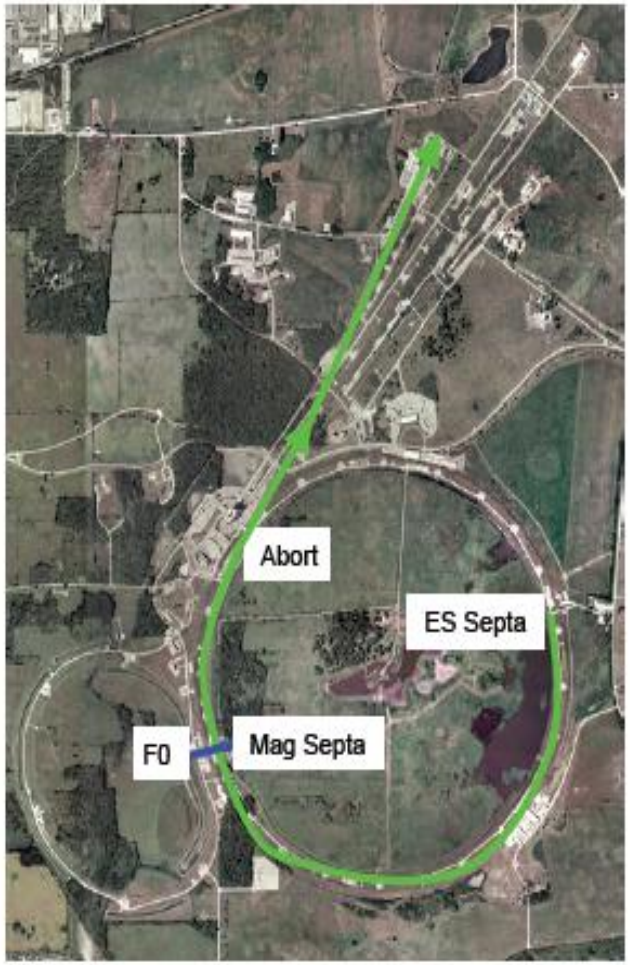
M. Syphers



- TeV circumference =2xMI
- Take two MI cycles to fill
- Use 2 cycles out of n, n>1, for use in TeV 120 the other n-2 used for NOvA.
- Slow Spill during the available n-1 MI cycles.

TeV Stretcher Implementation

- Can use the F0 injection septum as an extraction septum (needs polarity switch)
- Install electrostatic septum near F0, or perhaps C0.
  - C0 presently "unused"; ideal for $\frac{1}{2}$-integer extraction.
- Resurrect slow-spill feedback system ("QXR")



TeV Stretcher with 12 Booster batches

Max Tevatron intensity = 96 Tp = 9.6e13 at 120 GeV

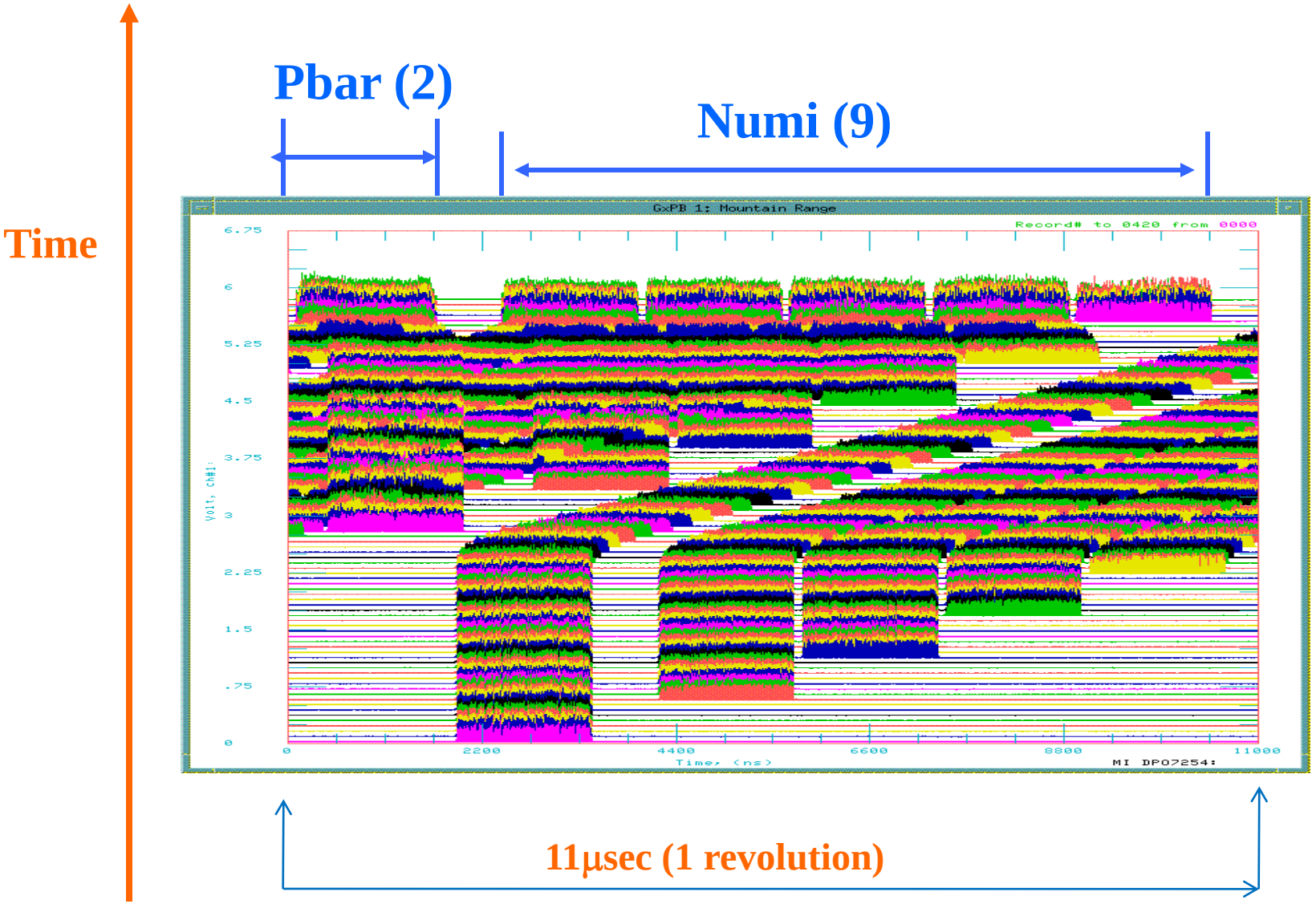
n	T[s]	df[%]	hit[%]	Pave[kW]	Pmax[kW]	NdotAve[Tp/s]	NdotMax[Tp/s]
2	2.667	50	100	691	1382	36.0	72.0
3	4.000	67	67	461	691	24.0	36.0
4	5.333	75	50	346	461	18.0	24.0
5	6.667	80	40	276	346	14.4	18.0
10	13.333	90	20	138	154	7.2	8.0
20	26.667	95	10	69	73	3.6	3.8
50	66.667	98	4	28	28	1.4	1.5
100	133.333	99	2	14	14	0.7	0.7
200	266.667	100	1	7	7	0.4	0.4

Conclusions

- After the collider run is over the Fermilab Accelerator complex will be re-configured for high intensity proton operations.
  - The Recycler is transformed into a proton pre-injector for MI.
  - The pbar rings will be re-congfigured for muon physics at 8 GeV.
  - The TeV can be used for fixed target physics.
- We have a list of Booster/Linac upgrades that are required for 15 Hz operation and the reduction of losses.
- The long Accelerator shutdown in FY12 is critical for the Booster upgrades and the 8 GeV muon physics program.

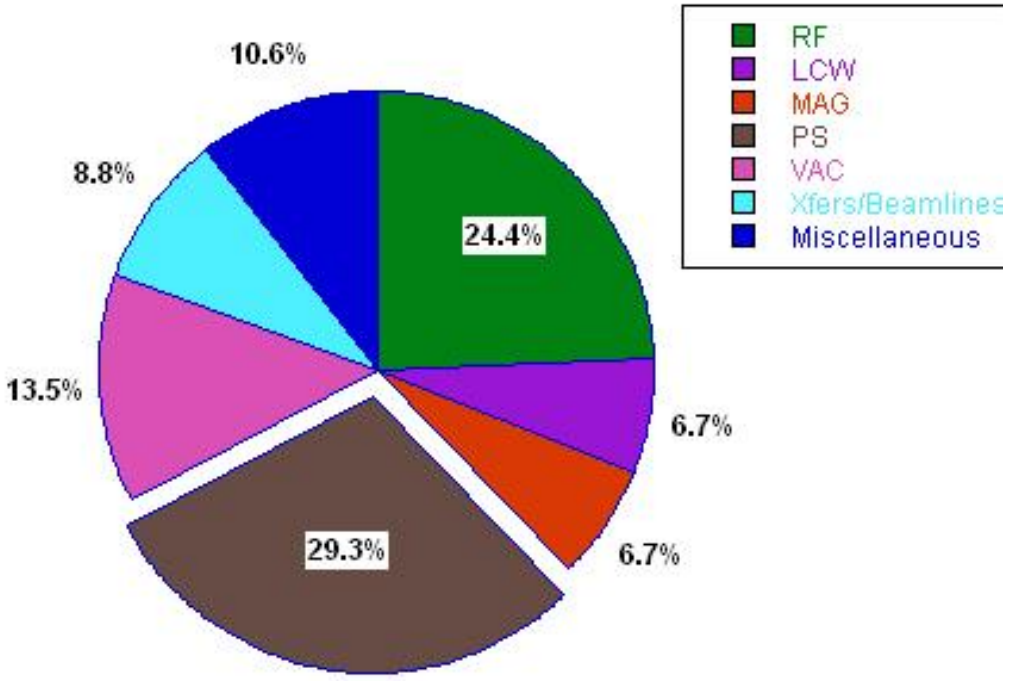
Extra slides

Mountain Range Picture of 11 Batch slip stacking

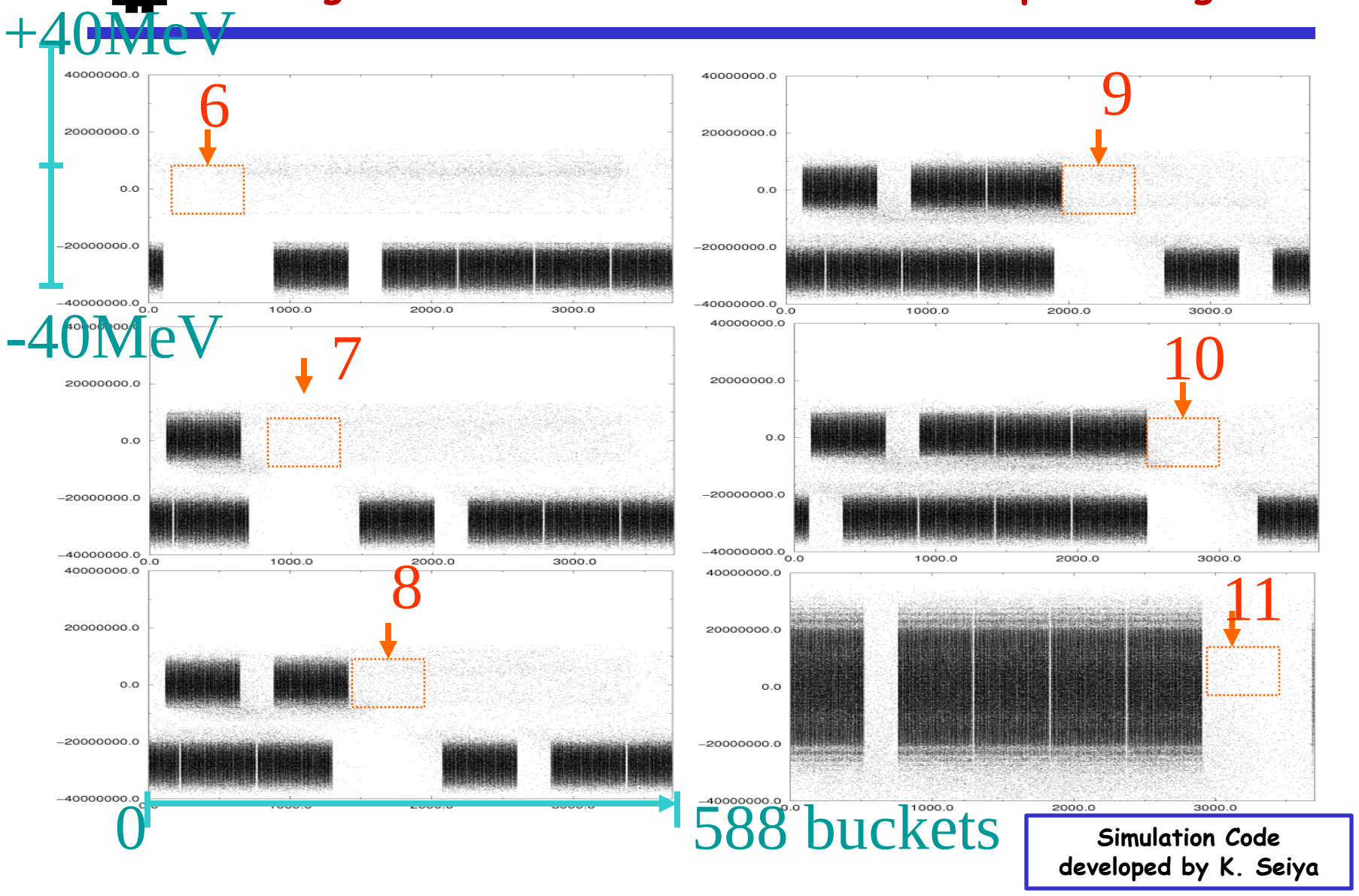


MI Downtime

- From January1, 2008 to April 3, 2009 the total MI downtime was 325 Hrs, i.e 3.8% of the total time.
- The biggest sources for downtime was the MI Rf and the Power Supplies.
- The rf requirements are larger because of the amount of the beam-loading compensation required during slip stacking and the amount of beam that is accelerated.

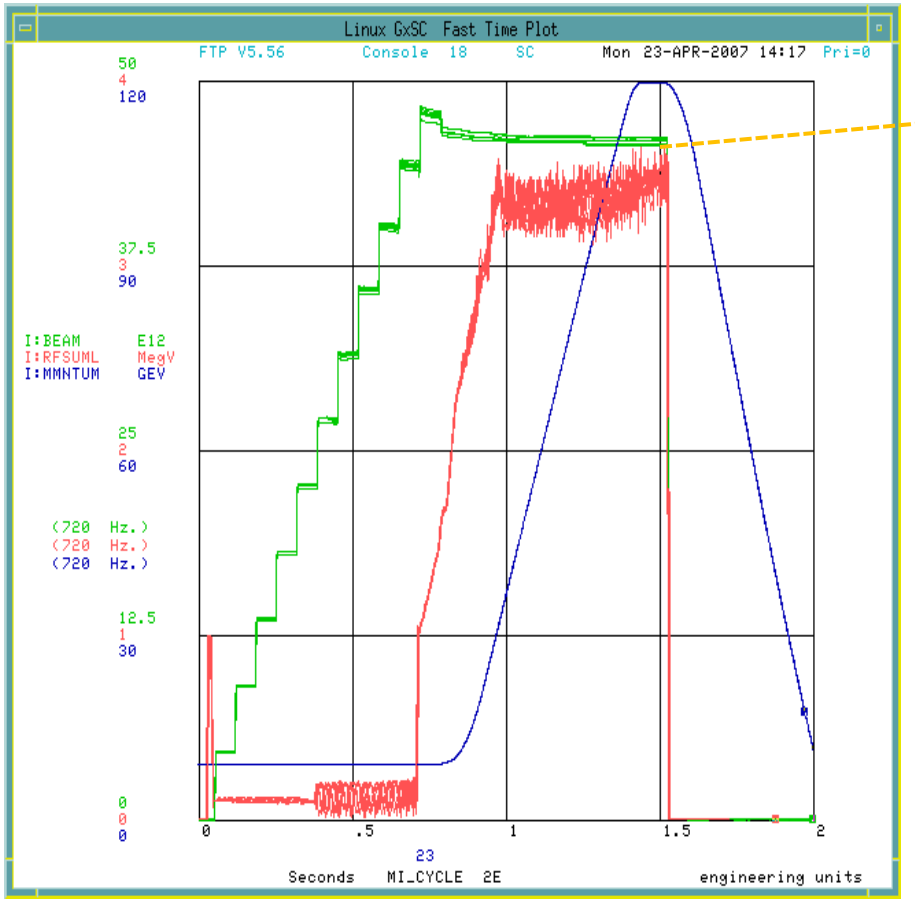


Longitudinal simulation for 11 batch slip stacking



Simulation Code developed by K. Seiya

MI Record Intensity



- 4.63E13 Protons to MI abort at 120 GeV.
- 92% Efficiency

Mu2e Alternatives